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Chapter 3
India's GHG Emission Reduction and Sustainable Development

P.R. Shukla and Subash Dhar

Abstract India has made voluntary commitment for reducing the emission intensity of GDP in the year 2020 by 20–25 % below that in the year 2005. The Indian approach is based on delineating and implementing cost-effective mitigation actions which can contribute to national sustainable development goals while remaining aligned to the UNFCCC's expressed objective of keeping the average global surface temperature increase to below 2 °C over the preindustrial average. This chapter assesses three emission scenarios for India, spanning the period 2010–2050. The analysis is carried out using a bottom-up energy system model ANSWER-MARKAL, which is embedded within a soft-linked integrated model system (SLIMS).

The central themes of the three scenario storylines and assumptions are as follows: first, a business-as-usual (BAU) scenario that assumes the socioeconomic development to happen along the conventional path that includes implementation of current and announced policies and their continuation dynamically into the future; second, a conventional low carbon scenario (CLCS) which assumes imposition, over the BAU scenario, of CO_2 emission price trajectory that is equivalent to achieving the global 2 °C target; and third, a sustainable scenario that assumes a number of sustainability-oriented policies and measures which are aimed to deliver national sustainable development goals and which in turn also deliver climate mitigation, resilience, and adaptation as co-benefits. The sustainable low carbon scenario (SLCS) also delivers same cumulative emissions from India, over the period 2010–2050, as the CLCS scenario using carbon price as well as a mix of sustainability-oriented policies and measures.

The scenario analysis provides important information and insights for crafting future policies and actions that constitute an optimal roadmap of actions in India which can maximize net total benefits of carbon emissions mitigation and national sustainable development. A key contribution of the paper is the estimation of the net social value of carbon in India which is an important input for provisioning carbon finance for projects and programs as an integral part of financing NAMAs.

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The analysis in the paper will be useful for policymakers seeking to identify the CO_2 mitigation roadmap which can constitute an optimal mix of INDCs for India.

Keywords Climate agreement • Sustainable development • Scenario modeling • Mitigation options • CO_2 Price • Social cost of carbon • $PM_{2.5}$ emission

Key Message to Policymakers

- India's CO_2 intensity declines in BAU yet inadequate for global low carbon goal.
- Carbon price affects energy supply side and leads to high share of nuclear energy and CCS.
- Sustainability policies reduce energy demand and enhance share of renewables.
- Low carbon policies aligned to sustainability goals deliver sizable co-benefits.
- Sustainability scenario delivers same carbon budget with lower social cost of carbon.

3.1 Introduction

India has endorsed the long-term target of limiting the temperature rise to under 2 °C (GoI 2008) and has also made voluntary commitment for reducing the emission intensity of GDP in the year 2020 by 20–25 % below that in the year 2005 at COP15 in Copenhagen. The "National Action Plan on Climate Change (NAPCC)" released by the Prime Minister's Office in June 2008 considers mitigation and adaptation actions implemented through eight National Missions (Table 3.1) to which the current government has added four more missions: wind, waste to energy for mitigation, and coastal and human health for adaptation.

The Indian approach to climate change is based on delineating and implementing cost-effective mitigation actions which can contribute to national sustainable development goals while remaining aligned to the UNFCCC's expressed objective of keeping the average global surface temperature increase to below 2 °C over the preindustrial average.

3.2 Model and Scenarios

3.2.1 Assessment Methodology and Model System

The integrated framework proposed in Fig. 3.1 falls under the earlier AIM family of models (Kainuma et al. 2003; Shukla et al. 2004). The bottom-up analysis is done

Table 3.1 Eight National Missions for climate change

Sr. No.	National mission	Targets
1	National solar mission	Specific targets for increasing use of solar thermal technologies in urban areas, industry, and commercial establishments
2	National mission for enhanced energy efficiency	Building on the energy conservation Act 2001
3	National mission on sustainable habitat	Extending the existing energy conservation building code, integrated land-use planning, achieving modal shifts from private to public transport, improving fuel efficiency of vehicles, alternative fuels, emphasis on urban waste management and recycling, including power production from waste
4	National water mission	20 % improvement in water use efficiency through pricing and other measures
5	National mission for sustaining the Himalayan ecosystem	Conservation of biodiversity, forest cover, and other ecological values in the Himalayan region, where glaciers are projected to recede
6	National mission for a "Green India"	Expanding forest cover from 23 to 33 %
7	National mission for sustainable agriculture	Promotion of sustainable agricultural practices
8	National mission on strategic knowledge for climate change	The plan envisions a new Climate Science Research Fund that supports activities like climate modeling and increased international collaboration; it also encourages private sector initiatives to develop adaptation and mitigation technologies

by the MARKAL model (Fishbone and Abilock 1981). MARKAL is an optimization mathematical model for analyzing the energy system and has a rich characterization of technology and fuel mix at end-use level while maintaining consistency with system constraints such as energy supply, demand, investment, and emissions (Loulou et al. 2004). The ANSWER-MARKAL model framework has been used extensively for India (Shukla et al. 2008, 2009; Dhar and Shukla 2015).

AIM/CGE and GCAM are top-down, computable general equilibrium (CGE), models used to compute the GDP loss and CO_2 price for the 2 °C stabilization scenario. AIM/CGE has been developed jointly by the National Institute for Environmental Studies (NIES), Japan, and Kyoto University, Japan (AIM Japan Team 2005). The model is used to study the relationship between the economy and environment (Masui 2005).

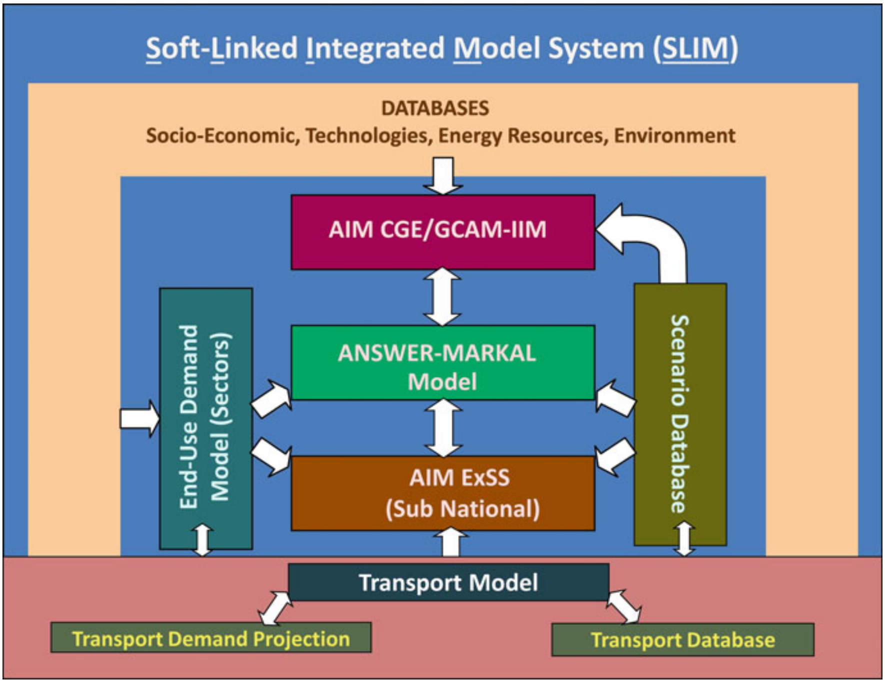


Fig. 3.1 Integrated model system

3.2.2 Scenarios Description

3.2.2.1 Business-as-Usual (BAU) Scenario

The BAU scenario considers the future economic development will copy the resource-intensive development path followed by the developed countries. The annual GDP growth rate is 8 % for the 17 years (2015–2032) and matches with the economic growth projections for India (GoI 2006, 2011). The GDP growth is expected to slow down post 2030, and the growth for overall scenario horizon, i.e., 2010–2050, is at a CAGR of 7 %. The rate of population growth and urbanization follows the UN median demographic forecast (UNPD 2013), and accordingly, the overall population is expected to increase to 1.62 billion by 2050. This scenario assumes a weak climate regime, and a stabilization target of 650 ppmv CO_2e is considered. The carbon price rises to a modest to $20 per ton of CO_2 in 2050 (Shukla et al. 2008).

3.2.2.2 Conventional Low Carbon Scenario (CLCS)

This scenario considers a strong climate regime and a stringent carbon tax post 2020. The underlying structure of this scenario is otherwise similar to the BAU. The scenario assumes stabilization target of 450 ppmv CO_2e. The CO_2 price trajectory assumes implementation of ambitious Copenhagen pledges post 2020, and CO_2 price trajectory therefore is below 15 US $ per t CO_2 till 2020 and then increases steadily to reach 200 US $ per t CO_2 by 2050 (Lucas et al. 2013). The scenario assumes greater improvements in the energy intensity and higher share of wind and solar renewable energy compared to the BAU scenario.

3.2.2.3 Sustainable Low Carbon Scenario (SLCS)

This scenario follows the "sustainability" rationale, similar to B1 global scenario of IPCC (2000). The scenario assumes decoupling of the economic growth from resource-intensive and environmentally unsound conventional path of the BAU. The scenario seeks to achieve by significant institutional, behavioral, technological (including infrastructures), and economic measures promotion of resource conservation, energy conservation, dematerialization, and demand substitution (e.g., telecommunications to avoid travel). The scenario also considers a strong push for exploitation of large renewable energy potential (GoI 2015) and increased regional cooperation among countries in South Asia (Shukla and Dhar 2009) for energy and electricity trade and effective use of shared water and forest resources.

The scenario considers socioeconomic and climate change objectives and targets (Fig. 3.2). The SLCS considers a strong climate regime and climate objective similar to CLCS. The SLCS considers a CO_2 budget equivalent to CLCS for the period 2010–2050. However, since CO_2 mitigation is a co-benefit of a number of sustainability actions, the social cost of carbon is expected to be lower than CLCS (Shukla et al. 2008).

3.3 Scenarios Analysis and Comparative Assessment

3.3.1 Energy Demand

The overall demand for energy in the BAU is expected to increase 3.6 times from 2011 to 2611 Mtoe in 2050. The compounded annual growth rate (CAGR) is 3.6 % for the period 2011–2050 which is slower than average GDP growth of 7.0 % which has been assumed for the economy. The decoupling between GDP and energy use is due to both structural changes within the economy (greater share of service sector) and improvement in technological efficiencies. The technological efficiency

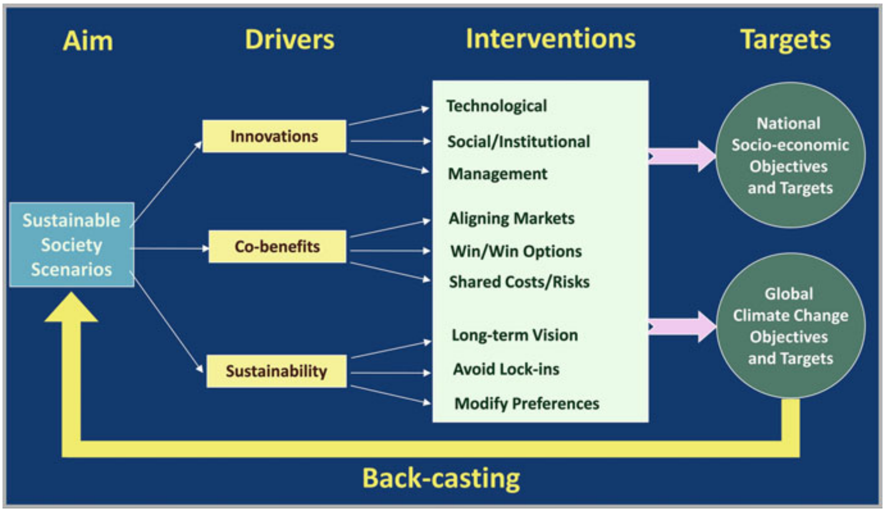


Fig. 3.2 Framework for the SLCS

improvement is most significant in the power generation where the net efficiencies improve from around 31.6 % to around 39 % in 2050.

The fuel mix is diversified in the BAU with nuclear energy, gas, and renewables taking a larger share of energy (Fig. 3.3). Coal however continues to remain the mainstay in the BAU scenario, and the bulk of coal is taken for power generation. Coal-based power generation capacity is expected to increase from 117 GW to 700 GW. Nuclear energy takes the next largest share of incremental demand for power generation, and by 2050 the installed capacity for nuclear energy is expected to increase to 200 GW from only 5 GW in 2010.

In the CLCS scenario, high carbon prices are able to bring down overall demand for energy in the medium term (by 2030); however, in the long term, the energy demand is only marginally lower than BAU (Fig. 3.4). A key reason for this is the large penetration of carbon capture and storage (CCS) in combination with coal-based power generation and steel production. CCS technology requires energy for CO_2 collection, transportation, and pumping into the storage and therefore imposes an energy penalty. The fuel mix is however diversified in a much stronger fashion with reference to the BAU, and the share of nuclear energy and renewables is much higher (Fig. 3.5).

In the SLCS energy demand is much lower (Fig. 3.4) since the demand for steel, cement, fertilizers, and many other energy-intensive commodities is much lower than BAU due to resource conservation and dematerialization. The energy demand is also lower from building, transport, and commercial sectors due to sustainable lifestyles. By 2050 the overall demand for energy is around one third lower than BAU. The fuel mix is also diversified; however, unlike CLCS, the reliance on nuclear energy and CCS is minimal and consistent with concerns with regard to their sustainability.

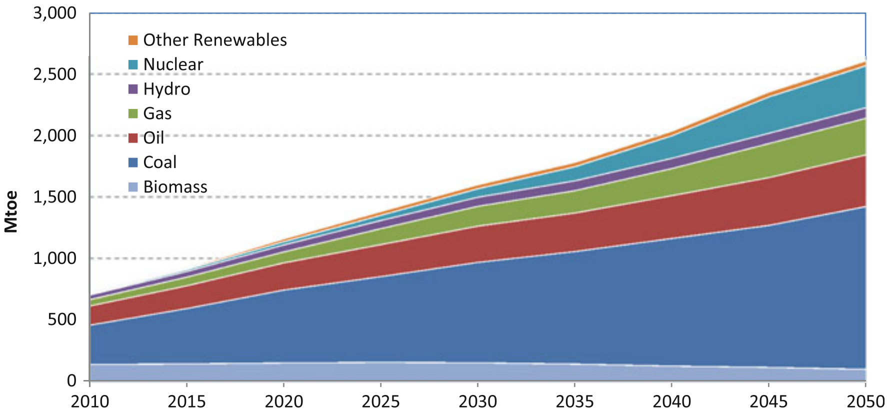


Fig. 3.3 Primary energy fuel mix and demand in the BAU

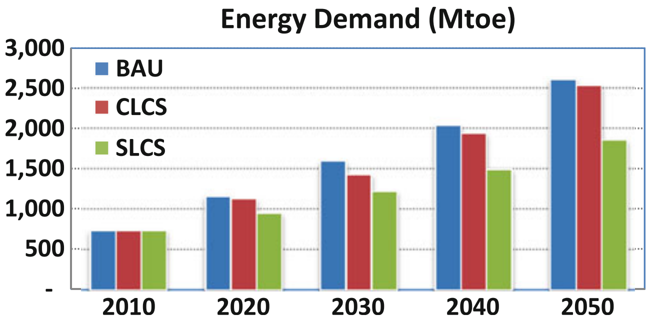


Fig. 3.4 Total primary energy demand in the BAU and low carbon scenarios

3.3.2 CO_2 Emissions and Mitigation Options

The CO_2 emissions from the energy use in the BAU increase 3.8 times between 2010 and 2050 and reach 7.32 billion tCO_2 in 2050. On a per capita basis, the emissions would be around 4.5 tCO_2 which is close to the current global average (IEA 2013). The bulk of the CO_2 emissions currently are attributable to the combustion of coal (Fig. 3.6), and this scenario would continue in the BAU in the absence of any strong climate policies.

Under both the low carbon scenarios, the growth in emissions can be limited (Fig. 3.7). In the conventional scenario, this is achieved by a small drop in energy demand (Fig. 3.4) and a sharp reduction in the share of coal from 51 % in BAU to 28 % in 2050 (Fig. 3.5). Coal is mainly substituted by nuclear energy and renewables. The share of renewable energy in 2050 is more than double from 9 % in BAU to 20 % in the CLCS (Fig. 3.5). Similarly, the share of nuclear energy is 23 % in 2050 in the CLCS. In addition coal use is increasingly decarbonized within power and steel sector with the introduction of carbon capture and storage (CCS). The total

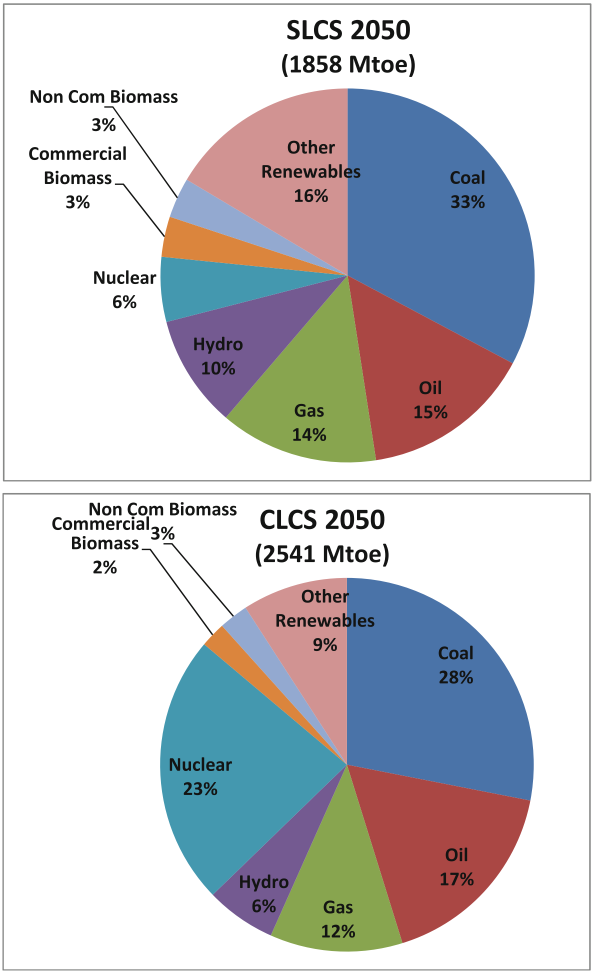


Fig. 3.5 Fuel mix in low carbon scenarios in 2050

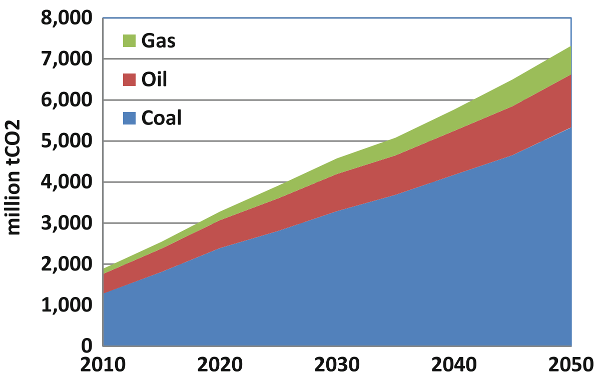
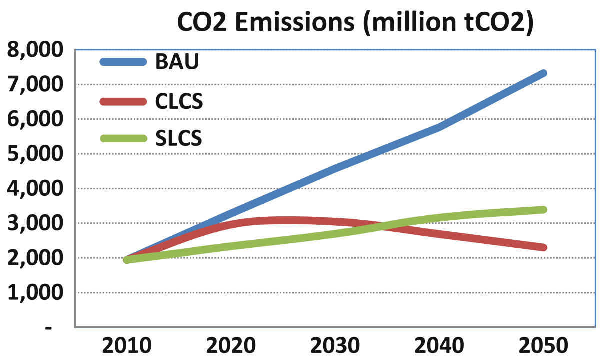


Fig. 3.6 CO_2 emissions in the BAU from energy use (million tCO_2)

Fig. 3.7 CO_2 emissions in the BAU and low carbon scenarios from energy use (million tCO_2)



amount of CCS that is sequestered till 2050 is 30.6 billion tCO_2. A storage of less than five billion tCO_2 is available within depleted oil and gas fields and in coal mines (Holloway et al. 2009), and at many locations, this would be proximal to large point source (Garg and Shukla 2009). The supply curve for CCS therefore allows mitigation at costs below US $ 60 per tCO_2 within power and steel sector for a cumulative storage of 5 billion tCO_2. Beyond this, we have considered saline aquifers in the sedimentary basin as an option, though there is not much research or government initiative at the moment to identify potential and sites for this. Therefore, increasing CO_2 price was considered for this CO_2 storage.

In the SLCS scenario, emissions are lower due to a much lower energy demand (Fig. 3.4) from BAU. The lower energy demand is due to a wide variety of measures related to sustainability which reduce demand for energy-intensive industries like steel, cement, bricks, aluminum, etc. The second major driver is renewable energy which provides for one third of primary energy.

3.4 Co-benefits of Mitigation

Climate change mitigation can deliver co-benefits or co-costs, and we examine the scenarios on two indicators: energy security and local environment.

3.4.1 Energy Security

Energy security has been defined as the risk to the country from negative balance of energy trade and risks due to supply (Correlje and van der Linde 2006). In this sense a reduction in demand for fuel or increase in diversity of supply (Dieter 2002) is good for energy security. In terms of overall demand, the CLCS has almost similar demand as the BAU, whereas in case of SLCS, the overall demand is only 71 % of BAU in 2050 (Fig. 3.8). The fossil fuel use declines in the CLCS scenario; however,

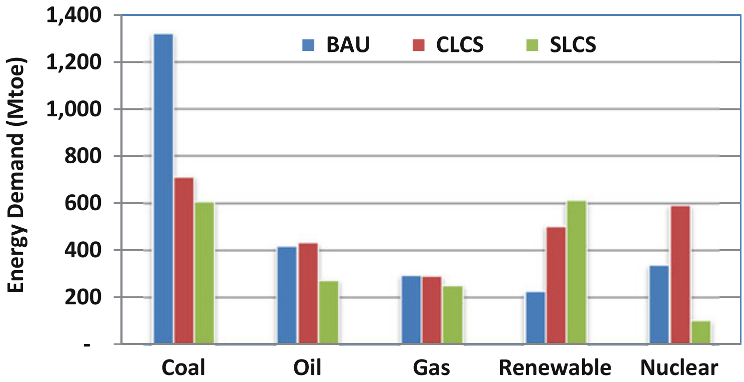


Fig. 3.8 Primary energy mix in 2050: BAU and low carbon scenarios

this is mainly due to a halving of demand for coal. Since India has a good resource availability for coal, the improvement in energy security would be small. In the SLCS scenario, the fossil fuel demand is lower for all fuels including oil, and since India depends for more than 80 % on imports of oil, improvements in energy security would be substantial. Indian nuclear energy establishment has propounded development of nuclear energy power using indigenously available thorium in the past (Kakodkar 2006); however, with signing of agreement with the nuclear energy suppliers group in 2008, India is able to import uranium. The planned nuclear energy power plants are all based on conventional fuel cycle with dependence on uranium, and therefore, higher nuclear energy will deteriorate energy security in the CLCS. In comparison the SLCS has a much lower share of nuclear energy which would help in improvement of energy security.

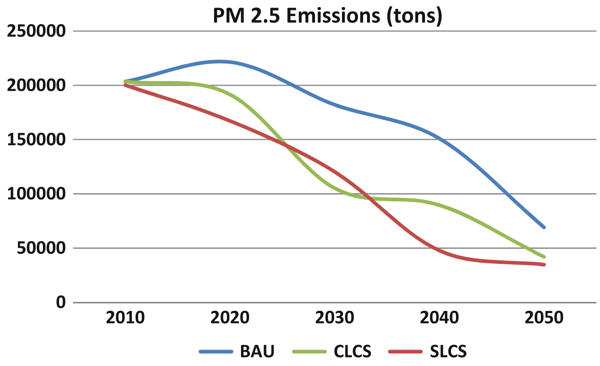
3.4.2 Environment

Many Indian cities have the very high levels of air pollution (WHO 2014) which is leading to serious health impacts (a. $PM_{2.5}$ is one of the key local pollutants and is responsible for severe health risks. Transport sector accounts for 30–50 % of the $PM_{2.5}$ (Guttikunda and Mohan 2014), and therefore, we analyze $PM_{2.5}$ for transport sector.

In India Bharat Stage III emission standard for motor vehicle (equivalent to Euro III) is applicable across India, and BS IV emission standards are applicable in the National Capital Region of Delhi and 20 other larger cities. Thirty additional cities are planned to move to Euro IV by 2015 (GoI 2014). In all the three scenarios, it is assumed that the BS IV would be fully implemented by 2020 all across India (GoI 2014).

The implementation of stricter emission norms which will entail changes to both vehicles and fuels will deliver for environment in the medium term (post 2025

Fig. 3.9 PM 2.5 emissions from transport sector across scenarios



onwards); however, air pollution would remain a challenge for the next 10 years. However, strong sustainability measures as envisaged in SLCS can help in turning the tide on air pollution quite early (Fig. 3.9). Similarly, a strong climate regime can also bring significant benefits for air quality (Fig. 3.9).

3.4.3 Net Social Cost of Carbon

The CO_2 mitigation is the same between the two low carbon scenarios. In conventional scenario, the mitigation actions are mainly a consequence of a high carbon price which increases rapidly post 2020 and with an expectation of a good climate treaty in 2015. The advance measures taken as a part of the sustainability paradigm can help to put the country on a trajectory where CO_2 mitigation is a co-benefit and, because of this, the society can achieve a similar amount of mitigation at a lower social cost of carbon (Fig. 3.10). This means if sustainability is limited to India, a higher mitigation corresponding to the global carbon price will occur, which can then be traded. If the sustainability paradigm is global, then a mild tax trajectory (Fig. 3.10) is required.

3.5 Conclusions

The chapter presented historical projections of energy and emissions in India under different scenarios. The approach followed in this paper visualizes low carbon transition in India from two different perspectives. First is the conventional perspective which assumes the rest of the economy is in competitive equilibrium. The approach visualizes carbon mitigation as an outcome of the application of a globally efficient carbon price in the form of a tax or a shadow price resulting from the global emissions carbon cap. This perspective, referred to as conventional low carbon scenario (CLCS), however discounts the fact that developing country

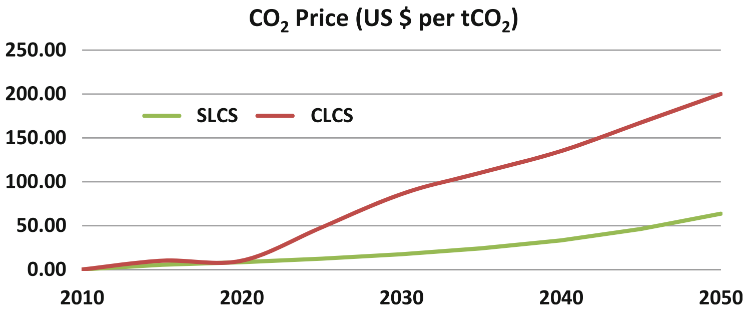


Fig. 3.10 Net social cost of carbon

economies have deep-rooted institutional weaknesses which impedes competitive behavior. The paper proposes a second scenario, referred to as sustainable low carbon scenario (SLCS), that explicitly recognizes the market weakness and hence explicitly implement additional policies which align the national sustainable development goals with the global low carbon objective.

As a reference point for the low carbon pathway, a business-as-usual (BAU) scenario is also assessed. A notable result is that energy demand and CO_2 emissions in India decouple significantly from GDP growth even in the BAU. However, the decoupling of CO_2 is not adequate when compared to what would a cost-effective global carbon regime targeting 2 °C temperature stabilization. Thus, further carbon mitigation is needed to align India's mitigation target with global stabilization.

Under CLCS, the application of global carbon price has little impact on energy demand, but it results in greater energy supply-side response like higher share of nuclear energy power and CCS. The projections show that by 2050, India can deploy nearly 30 billion tCO_2 sequestration capacity under CCS. This is much higher than what is available in depleted oil and gas wells and coal mines, and using this capacity at higher end can be extremely risky due to the uncertainty of the CCS capacity and costs in India. This aside, in this scenario, nuclear energy would supply nearly a quarter of the primary energy demand in 2050. This is also a high risk proposition given the uncertainty of the full cost of nuclear energy in India.

Under the SLCS, many sustainable development-focused measures such as designing and implementing sustainable habitat and mobility solutions, 3R (reduce, reuse, recycle) measures, and demand-side energy and resources management measures result in reducing the energy demand by a third in 2050. In addition, the policy support for renewable energy results in relatively minimal use of CCS which can be easily sequestered within the depleted oil and gas wells or coal mines in the country. The demand for nuclear energy power is also reduced significantly under this scenario. Solar and wind energy would play a bigger role in both CLCS and SLCS (Fig. 3.8). The energy security benefits, compared to BAU, are very high in SLCS but negligible in CLCS. Air quality benefits are high in both CLCS and SLCS.

In case of CLCS, the mitigation is achieved by applying the global carbon price over Indian economy. In case of SLCS, the emissions budget is assumed to be the same as the emissions in CLCS during the period 2010–2050. In SLCS, the emissions are at first reduced by various measures targeted to achieve national sustainable development goals. The budgeted carbon pathway is achieved by the shadow price of carbon corresponding to the budget constraint. This cost, which we refer to as the "social cost of carbon," is much lower in the case of SLCS since the carbon reduction that is delivered by the sustainability measures is assumed to be "free" since their cost is included in the cost-benefit assessment of national sustainability measures which typically do not include carbon benefits.

The assessment in the paper shows that aligning actions toward India's low carbon pathway with measures for achieving national sustainable development goals would result in significantly lower social cost of carbon for India. This signifies the existence of sizable co-benefits between low carbon and sustainable development actions. The methodology and analysis in this paper thus provides a way forward for scientifically delineating the Intended Nationally Determined Contributions (INDCs) for mitigation. The technological and financial details underlying the modeling analysis can be useful for preparing the road map of India's Nationally Appropriate Mitigation Actions (NAMAs) and downscale these to actionable projects with clearly identified pathways for technology development, transfer and deployment, as well as access to carbon finance.

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